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Title:
ELECTRONIC AEROSOL GENERATOR

Abstract:

An aerosol generator comprises a reservoir (5) for liquid to be dispensed and an exit cavity (1) having a plurality of exit orifices formed in an orifice plate (2). The cavity (1) is coupled to a piezoelectric transducer assembly (3) arranged to induce pressure variations in the exit cavity. A control circuit drives the transducer assembly at its resonant frequency so that droplets are simultaneously expelled from the orifices at the frequency to form an aerosol.

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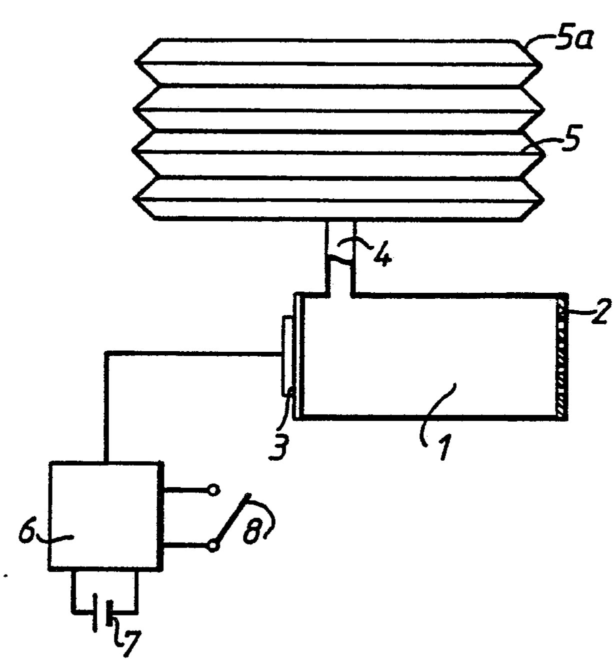

(57) Abstract

An aerosol generator comprises a reservoir (5) for liquid to be dispensed and an exit cavity (1) having a plurality of exit orifices formed in an orifice plate (2). The cavity (1) is coupled to a piezoelectric transducer assembly (3) arranged to induce pressure variations in the exit cavity. A control circuit drives the transducer assembly at its resonant frequency so that droplets are simultaneously expelled from the orifices at the frequency to form an aerosol.

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Electronic Aerosol Generator

The present invention relates to an aerosol generator and more particularly to a low cost electronic aerosol generator.

Aerosol generators are used in numerous applications for dispensing of liquids, such as perfumes, pharmaceuticals insecticide, paints etc., The most common principle used for generation of these aerosols is to force the liquid, using a drive gas such as freon, through a nozzle. This causes the liquid to break-up into individual droplets thus generating the aerosol.

Such aerosol generators have a number of disadvantages, the most pronounced being:

- freon is still the most commonly used drive gas causing well known pollution problems;

- the size distribution of the droplets in the aerosol is very wide, reducing its efficiency in some applications;

- in many applications an undesirably high exit speed of the droplets is caused, by the pressurised drive gas;

- it is difficult to control the dose which is dispensed with these aerosol generators.

One possible solution to these problems would be to provide an electrically controlled aerosol generator, in the form of a droplet generator similar to those used for ink-jet printing. In drop-on-demand ink-jet print heads, the formation of individual droplets is controlled precisely by an electrical voltage pulse. One system uses a piezoelectric device to compress the ink contained in a cavity. The compression of the ink in the cavity generates a pressure pulse, which travels towards a nozzle opening. If the amplitude of the pressure pulse is sufficiently high a droplet will be ejected from the nozzle. Once the oscillations of the ink in the cavity, caused by reflections of the pressure pulse, have died out, a new voltage pulse can be applied to the piezoelectric device and a new droplet ejected. It is possible to eject droplets at a frequency of a few kHz with these systems.

An evaluation of this type of electroacoustic droplet generator for use in aerosol generation, has shown that the liquid flow which can be dispensed is very small and insufficient for most applications. The droplet size is too large and if the nozzle diameter is reduced, then the system cannot generate sufficient pressure to eject the droplets. The kinetic energy contained in the droplets is insufficient to give any significant throw length of the droplets. Furthermore, the overall construction of the generators and the drive electronics are complex making such devices unsuitable for low cost disposable or semi-disposable applications.

It would therefore be desirable to provide an electronic aerosol generator which did not suffer from the problems associated with the type of droplet generator described above.

The present invention provides an aerosol generator comprising a reservoir for fluid to be dispersed and an exit cavity communicating with the reservoir, the exit cavity having a plurality of exit orifices and being coupled to a piezoelectric transducer assembly arranged to induce variations in pressure in the exit cavity, and a control circuit for driving the piezoelectric transducer assembly at one of its resonant frequencies.

The exit cavity and piezoelectric transducer assembly effectively act as a pump ejecting liquid droplets at the resonant frequency of the transducer assembly. By operating at resonance and by using a large number of small exit orifices it is ensured that a high volume of liquid is ejected at high frequency resulting in efficient aerosol generation. Typical operating frequencies are in the range 10-200 kHz, depending on the construction of the transducer assembly and the liquid to be ejected.

To ensure efficient aerosol generation, the fluid pressure variations at the orifices caused by vibrations of the transducer assembly should be maximised. If the exit cavity is not appropriately constructed, the vibrations of the transducer assembly could merely cause turbulence at the exit orifices which is not sufficient to achieve droplet ejection.

In the preferred embodiment of the invention the distance between the transducer assembly and the exit orifices is chosen to be very short to avoid acoustic vibrations in the liquid. To this end, the distance between the transducer assembly and the exit orifices should be small relative to the wavelength of sound in the liquid to be dispersed. With such an arrangement acoustic vibrations are minimised and vibrations of the transducer assembly result directly in

pressure variations at the exit orifices.

In an alternative embodiment of the invention the exit cavity is constructed as a resonant cavity tuned to the resonant frequency of the transducer assembly whereby resonant standing waves are generated with a pressure antinode at a wall portion of the cavity. The exit orifices are provided at this wall portion. The result is a high pressure variation at the exit orifices which results in synchronous ejection of droplets from the individual orifices. In this way it is possible to generate an aerosol consisting of several streams of droplets. With the generator tuned to eject droplets at resonance, the required electrical energy input is very low and the electronic drive circuit can be kept very simple.

For both of the embodiments of the invention described above, the cavity is preferably a cylindrical tubular member closed at one end by a plate in which the exit orifices are formed and at the other end by the piezoelectric transducer assembly. For the first mentioned embodiment the tubular member will be very short; for the second embodiment the length of the tubular member will be selected to generate the required mode of oscillation.

In order that the present invention may be more readily understood, an embodiment thereof will now be described by way of example, with reference to the accompanying drawings, in which;

Figure 1 shows a schematic drawing of a first embodiment of the invention;

Figure 2 shows a more detailed drawing of the resonating pipe assembly of Figure 1;

Figure 3 shows a more detailed circuit diagram of the preferred drive electronics for the embodiment of Figure 1; and

Figure 4, shows a schematic drawing of a second embodiment of the invention.

Referring to Figure 1, the aerosol generator consists an exit cavity in the form of a pipe section 1, typically of a round cross section, closed at one end by an orifice plate 2 and at the other end by a piezoelectric transducer assembly 3. The pipe section 1 is connected via a filling tube 4, to a fluid reservoir 5, containing the liquid to be atomised. The piezoelectric transducer 3, is electrically connected to an oscillator circuit 6, including a battery 7 and a switch 8.

When the switch 8 is activated, the piezoelectric transducer assembly 3 is energized by the oscillator circuit 6 and caused to vibrate at its resonance frequency, and generate pressure waves in the liquid in the pipe section 1. The length of the pipe 1 is chosen such that, a strong pressure oscillation within the liquid can be created due to resonating standing pressure waves. By appropriate design an approximate antinode of a standing pressure wave can be generated at the orifice plate 2. The orifice plate 2, is a thin plate, containing a multiple number of small orifices. The liquid will by capillary forces be drawn into each orifice, and form a meniscus on the outer surface of the orifice plate 2. The pressure oscillations caused by the antinode of the standing pressure waves in the pipe section 1, forces the meniscuses out of the orifices during the compression cycle, and if the pressure is high enough, the meniscuses will separate and break up into individual droplets. During the expansion cycle, the reduced pressure in the pipe section will cause fluid to be sucked into the pipe section from the reservoir. At the same time, the meniscus may retract to some extent

into the orifices and it is important, that the length of the orifices is sufficient to avoid air, being withdrawn into the pipe section 1. To avoid generation of a negative pressure, compared to ambient pressure, the reservoir 5, is preferably of a collapsible type, which compensates for the liquid volume which has been ejected. In the embodiment of the invention shown in Figure 1, the reservoir has side walls 5a formed as a bellows arrangement which collapses as the volume of fluid in the reservoir decreases. Alternatively, the reservoir may simply comprise a collapsible bag.

It is possible to combine the activation of the contact 8, with a mechanical cleaning and/or closing function of the front surface of the orifice plate 2, to prevent dirt from entering the orifices.

Figure 2 shows the resonating pipe assembly in more detail. The preferred piezoelectric transducer assembly is a flexure construction, consisting of a round diaphragm, having a diameter D, onto which has been bonded a thin piezoelectric ceramic element 10. When the piezoelectric element 10 is activated with a voltage across its thickness, it will expand or contract, causing the diaphragm 9 to deflect inwards or outwards. The mechanical resonance frequency, F_r, of this flexure element can be approximated as:

$$F_r = K_n \left(\frac{h}{D^2}\right) \quad (1)$$

where h is the thickness of the metaldiaphragm and K_n is a material constant depending on the mode of vibration.

The length L of the pipe section 1 is chosen such that when the transducer assembly 3 vibrates at its resonance frequency, a resonating standing wave pattern is generated in the pipe section, resulting,

approximately in a pressure antinode at the orifice plate 2 and a pressure node at the transducer 3. The length L of the pipe can approximately be determined from the following expression:

$$L = \frac{c}{4.F_r} \qquad (2)$$

where F_r is the transducer resonance frequency given by equation (1) and c is the velocity of sound in the liquid. Calculated by this expression, the liquid column in the pipe section 1 will oscillate at its fundamental resonance frequency. It is also possible to activate other resonance frequencies which result in droplet ejection.

The orifice plate 2 is preferably produced by electroforming or chemical milling processes, allowing a multiple number of precise defined orifices to be implemented at low cost. Suitable dimensions for the orifices would be 20 μm diameter in a plate 40 μm thick.

Figure 3 shows the diagram of a preferred electronic drive circuit for the aerosol generator. With this circuit the transducer oscillates in a self-excited mode reflecting the resonances of both the transducer and the pipe section. For this purpose the piezoelectric ceramic element 11 has three electrodes. It is an important aspect of the overall design, that at resonance the transducer impedance is at a minimum, when the correct standing wave pattern is generated in the pipe section 1. This allows the oscillator circuit to compensate automatically for changes in the resonance

frequency due to temperature effects, or mechanical tolerances on the components.

It is possible to combine this electronic drive circuit with other functions such as automatic dispensing at programmed time intervals, or a timer to give an exact dose every time the device is activated.

An alternative embodiment of the present invention is illustrated schematically in Figure 4. Items in Figure 4 corresponding to items in Figure 1 are indicated by like reference numerals, increased by 100.

The most important difference between the arrangements of Figures 1 and 4 is that in Figure 4 the resonating pipe has been replaced by a cavity 102. Cavity 102 is preferably a circular pipe section closed at one end by an orifice plate 102 and at the other end by a piezoelectric transducer assembly 103. In contrast to the arrangement of Figure 1, the distance between the transducer assembly 3 and the orifice plate 2 is short in comparison to the wavelength of sound in the fluid to be dispensed. As a result, instead of pressure waves being set up in the fluid, movements of the transducer assembly are transmitted directly through the fluid to the orifice plate. The transducer assembly may be the same as that described above in relation to Figure 3. Thus, as the flexure element bows inwardly the pressure in the cavity is increased and fluid is forced out of the orifices to form an aerosol in the space outside the orifices. Then, as the flexure element bows outwardly, the pressure in the cavity is reduced and fluid is drawn into the cavity from the reservoir. At the same time the meniscuses of the fluid in the orifices will retract to some extent towards the cavity, as mentioned above, in relation to Figure 2.

For generating an aerosol the length L of the

cavity may suitably be about 1mm.

As with the arrangement of Figure 1, when a switch 108 is activated, the piezoelectric transducer assembly is energised by an oscillator circuit 106 to vibrate at its resonant frequency. The oscillator circuit 106 is powered by a battery 107.

The reservoir 105 illustrated in Figure 4 comprises a collapsible bag but it could equally well comprise a bellows arrangement of the type shown in Figure 1.

In all other respects the aerosol generator of Figure 4 is similar to that of Figure 1 and it will be understood that the possible modifications described in relation to the first embodiment are equally applicable to the embodiment of Figure 4.

Claims:

1. An aerosol generator comprising a reservoir for fluid to be dispersed and an exit cavity communicating with the reservoir, the exit cavity having a plurality of exit orifices being coupled to a piezo electric transducer assembly arranged to induce variations in pressure in the exit cavity, and a control circuit for driving the piezoelectric transducer assembly at one of its resonant frequencies.

2. An aerosol generator as claimed in claim 1, in which the piezoelectric transducer assembly comprises a flexure element having a piezoelectric ceramic element bonded thereto, such that changes in dimension of the piezoelectric ceramic element induce flexing of the flexure element.

3. An aerosol generator as claimed in claim 1 or 2 in which the orifices are formed in a wall portion of the cavity by electroforming.

4. An aerosol generator as claimed in claim 1, 2 or 3 in which the dimensions of the cavity are chosen such that, in use, vibrations of the piezoelectric transducer assembly generate resonant standing waves in fluid contained in the cavity, the mode of oscillation being such that an approximate pressure antinode is generated at a wall portion of said cavity, the exit orifices being formed in said wall portion.

5. An aerosol generator as claimed in any preceding claim in which the exit cavity comprises a hollow cylindrical member, one end of which is closed by a plate in which the exit orifices are formed and the other end of which is closed by the piezoelectric transducer assembly.

6. An aerosol generator as claimed in any preceding claim in which the reservoir comprises a collapsible housing.

7. An aerosol generator as claimed in any preceding claim in which the control circuit includes an oscillator circuit connected to a power source and switch means between the oscillator circuit and the power source.

8. An aerosol generator as claimed in claim 7 in which the control circuit further includes means for activating said oscillator at predetermined time intervals.

9. An aerosol generator as claimed in claim 7, in which the control circuit further includes means responsive to said switch means for activating said oscillator for a predetermined length of time to dispense a predetermined amount of fluid.

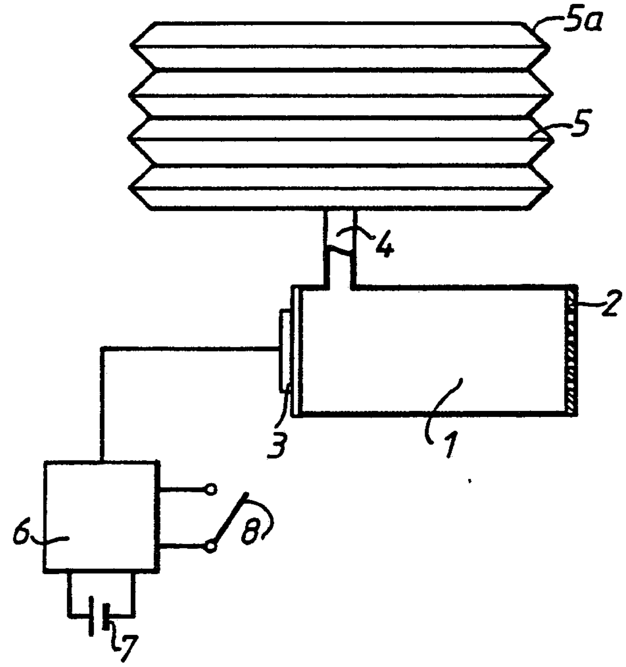

Fig.1.

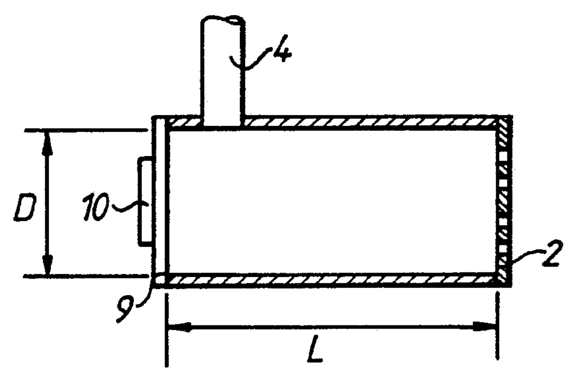

Fig.2.

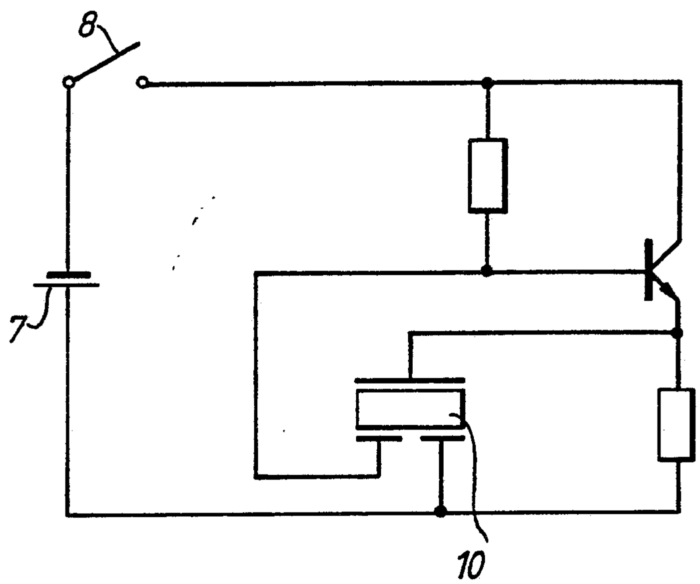

Fig.3.

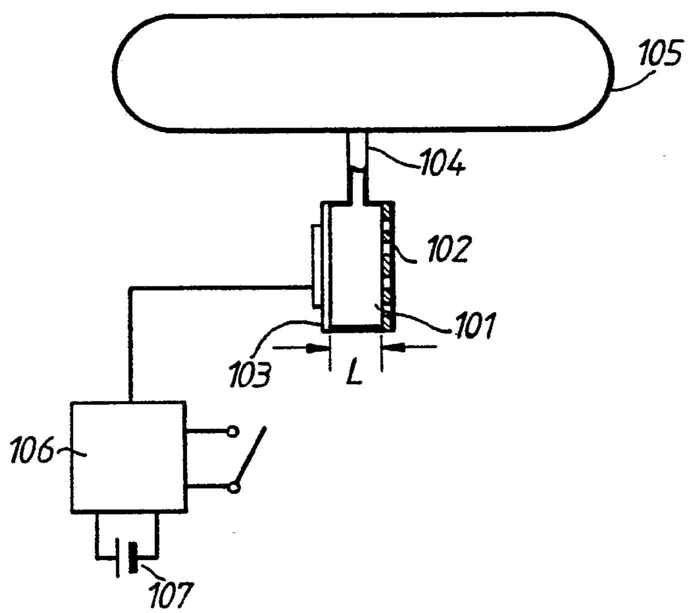

Fig.4.

INTERNATIONAL SEARCH REPORT

International Application No PCT/GB 89/00944

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [6]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC^5: B 05 B 17/06

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
IPC^5	B 05 B; A 61 M

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category [*]	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No. [13]
X	Review of Scientific Instruments, vol. 58, no. 7, July 1987, American Institute of Physics (New York, N.Y., US) N. Ashgriz et al.: "Development of a controlled spray generator", pages 1291-1296, see page 1292, right-hand column, line 1 - page 1293, left-hand column, line 32; figure 2 --	1,2,5
X	EP, A, 0049636 (MATSUSHITA) 14 April 1982, see page 11, line 27 - page 13, line 13; figures 2-7,8-13 --	1,2,5
A	US, A, 2512743 (HANSELL) 27 June 1950, see column 4, lines 48-56; figure 1 --	1,2
A	GB, A, 2099710 (ROWENTA) 15 December 1982, see the abstract --	6
A	Patent Abstracts of Japan, vol. 9, no. 66 (C-271)(1789), 26 March 1985 ./.	7-9

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"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
27th November 1989	18. 12. 89
International Searching Authority	**Signature of Authorized Officer**
EUROPEAN PATENT OFFICE	T.K. WILLIS

Form PCT/ISA/210 (second sheet) (January 1985)

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)		
Category *	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No
	& JP, A, 59199074 (MATSUSHITA DENKI SANGYO K.K.) 12 November 1984 ----	

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON INTERNATIONAL PATENT APPLICATION NO. GB 8900944 SA 30768

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report.
The members are as contained in the European Patent Office EDP file on 08/12/89
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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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		JP-A- 57068164	26-04-82
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GB-A- 2099710	15-12-82	DE-C- 3122681	16-12-82
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		NL-A- 8202262	03-01-83

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